Tetrahedron Letters No. 15, pp 1477 - 1480, 1972. Pergamon Press. Printed in Great Britain.

p-METHYLANISOLE AS AN AMBIDENT BASE. EFFECT OF ACID STRENGTH ON THE POSITION OF PROTONATION

John W. Larsen and M. Eckert-Maksic[1]
Department of Chemistry, University of Tennessee
Knoxville, Tennessee 37916

(Received in USA 8 February 1972; received in UK for publication 3 March 1972)

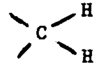
It has long been recognized that phenols and anisoles can serve as ambident bases in strong acids, protonating either on a ring carbon atom or on oxygen.[2] There has been a great deal of interest in these bases quite recently[3] and additional nmr evidence for the ambident character of phenols and their derivatives in strong acids has appeared.[4] We wish to report that the ambident behavior of substituted phenols and anisoles is a function of acid strength and temperature and can be used as a probe of solute-solvent interactions in superacid media.

The protonation of phloroglucinol and its methyl ethers show different solvent dependencies which have been ascribed to differing abilities of the phenols and eithers to derive stabilization through hydrogen bonding to the solvent.[5,6] It has been reported that in HF/BF_3, anisole protonates either on the oxygen atom or the 4-position and that the ratio of ring to oxygen protonation is strongly temperature dependent.[7,8] In fluorosulfonic acid only ring protonation of anisole is observed,[9,10,11] in contrast to the results in HF. In HF solutions, p-methylanisole protonates only on the oxygen atom.[7,12] It is clear that the ambident behavior of phenols and anisoles is quite sensitive to their solvent environment. We have observed that in fluorosulfonic acid and mixtures of antiomony pentafluoride with fluorosulfonic acid, p-methylanisole is protonated on either the oxygen atom or on the ring in the 2 position. Furthermore, the ratio of ring to oxygen protonation is a function of 1) the concentration of antiomony pentafluoride in the fluorosulfonic acid; 2) temperature; 3) the concentration of p-methylanisole; 4) the concentration of other solutes in the acid (e.g., SO_2 or H_2O). This equilibrium between the two different ions serves as a useful probe of the solvating characteristics of strong acid solutions for different types of cations.

Since p-methylanisole is known to sulfonate readily,[13,14] a series of control experiments designed to detect sulfonation were done. The nmr spectra at low temperatures contained no peaks attributable to sulfonated p-methylanisole. Quenching the solution in water or methanol gave back p-methylanisole in ca. 80% yield. Thus sulfonation is not occurring.

The nmr spectrum of oxygen protonated p-methylanisole has been reported previously.[7] Our observations, recorded in Table 1, agree quite well with the published spectra. The assignments for the ring protonated ion are also given in Table 1 and are indicative of protonation ortho to the methoxy group. The singlet at 4.38 δ due to the methylene group is characteristic of ring protonation.[4,7,8] Coupling between a methylene and adjacent ring protons has not been observed. The other chemical shifts assigned to this ion are similar to those observed by Hartshorn.[4] The nmr spectrum of p-methylanisole in mixtures of antimony pentafluoride and fluorosulfonic acid are shown in Fig. 1. In all cases the concentration is ca. 300 mg of p-methylanisole in 3 ml of acid. Spectrum e shows the compound in neat fluorosulfonic acid at -60°. This spectrum did not vary as the temperature was changed from -40 to -80°, indicating that, in this solvent, the enthalpies of protonation on carbon and oxygen are the same. Thus the entropy of oxygen protonation is more favorable since more of the oxygen protonated ion is formed. This entropy difference suggests not only that the two cations are solvated differently (the starting material and anions formed must be identical), but also that more solvent organization is required to solvate the ring protonated species than is required for the oxygen protonated species.

Table 1. Chemical Shifts for p-Methylanisole and Protonated p-Methylanisole

Compound	Ar-CH_3	-O-CH_3	Ring Protons	$-\overset{H}{O}^{+}-$	
p-methylanisole[a]	2.25	3.71	6.69,6.97	---	---
o-protonated[b]	2.48	4.75	7.48	11.9	---
o-protonated[c]	2.51	4.80	7.48	12.58	---
ring protonated[b]	2.38	4.50	8.55(m)[d] 7.40(m)	---	4.38

[a] In CCl_4. [b] In SbF_5/FSO_3H mixtures. [c] In HF/BF_3 mixtures, see refs. 7 and 8. [d] (m) Multiplet.

Spectra b, c, and d in Fig. 1 show the effects of increasing antimony pentafluoride concentration on the equilibrium between oxygen and ring protonation. The spectra were recorded at -40° in fluorosulfonic acid solutions containing 30%, 20%, and 10% antiomony pentafluoride by weight respectively. There is a striking increase in the concentration of the ring protonated ion with a corresponding decrease in oxygen protonation as the antimony pentafluoride concentration increases. It is obvious from this behavior that different bases will require different acidity functions in antimony pentafluoride-fluorosulfonic acid mixtures, just as they do in sulfuric acid-water mixtures.[15,16] Spectra a and b (Fig. 1 obtained at -80° and -40° respectively) show the effect of temperature on the ring/oxygen ratio in 30% SbF_5/FSO_3H. At the lower temperature, more oxygen protonation is observed, indicating that this is the more exothermic process. The same trend is observed in the ring/oxygen ratio of protonated anisole in HF/BF_3.[7] Since oxygen

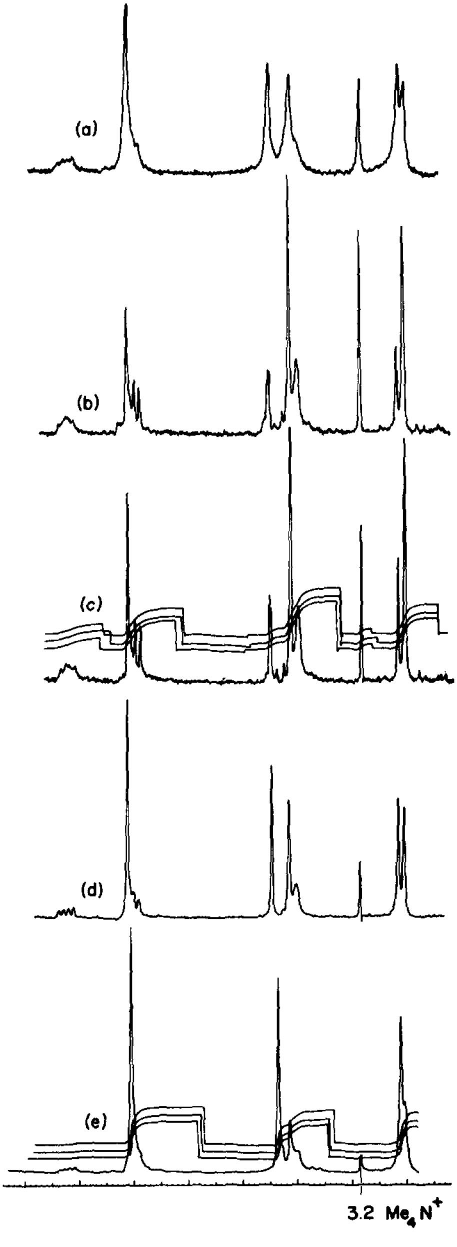


Figure 1 Nmr Spectra of Protonated p-Methylanisole in Mixtures of Antimony Pentafluoride and Fluorosulfonic Acid a) 30% SbF_5/FSO_3H (w/w) at -80°; b) 30% SbF_5/FSO_3 at -40°; c) 20% SbF_5/FSO_3H at -40°; d) 10% SbF_5/FSO_3H at -40°; e) neat FSO_3H at -60°

protonation is more exothermic than ring protonation, and more ring protonation than oxygen protonation is observed in 30% antimony pentafluoride-fluorosulfuric acid at -40°, the entropy term must favor ring protonation in this medium at this temperature. This behavior is opposite to that observed in neat fluorosulfonic acid. Apparently there are significant differences in the solvent characteristics of neat fluorosulfonic acid and its mixtures with antimony pentafluoride. Similar studies have been carried out with a number of other bases and a detailed thermodynamic analysis will be reported in a full paper. The equilibria involved are quite sensitive to substituent changes on both the ring and the oxygen atom.

Acknowledgement: Acknowledgement is made to the donors of the Petroleum Research Fund, administered by the American Chemical Society, for partial support of this work. Partial support by the National Science Foundation is also gratefully acknowledged.

References

1. On leave from the Institute Ruder Moskovič, Zagreb, Yugoslavia.
2. D. M. Brouwer, E. L. Mackor, and C. MacLean in Carbonium Ions, Vol. 2, P. von R. Schleyer and G. P. Olah, eds., John Wiley and Sons, N.Y., 1970.
3. A. J. Kresge, Y. Chiang, and L. E. Hakka, J. Amer. Chem. Soc., 92, 6167 (1971); A. J. Kresge, Y. Chaing, L. E. Hakka, and J. E. Kouba, ibid., 92, 6174 (1971); A. J. Kresge, S. G. Mylonakis, Y. Sato, and V. P. Vitullo, ibid., 92, 6181 (1971).
4. M. P. Hartshorn, K. E. Richard, J. Vaughan, and G. J. Wright, J. Chem. Soc., (B), 1624 (1971).
5. W. M. Schubert and R. H. Quacchia, J. Amer. Chem. Soc., 85, 1278 (1963); 84, 3778 (1962).
6. A. J. Kresge and Y. Chiang, ibid, 89, 4411 (1967); A. J. Kresge, Y. Chiang, and Y. Sato, 89, 4418 (1967).
7. D. M. Brouwer, E. L. Makor, and C. MacLean, Rec. Trav. Chem. des Pays Bas., 85, 109 (1966).
8. D. M. Brouwer, E. L. Mackor, and C. MacLean, ibid, 85, 114 (1966).
9. T. Birchall and R. J. Gillespie, Can. J. Chem., 42, 502 (1964).
10. C. MacLean and E. L. Mackor, Disc. Faraday Soc., 34, 165 (1962).
11. D. M. Brouwer, C. MacLean, and E. L. Mackor, ibid, 39, 121 (1963).
12. See, however, A. J. Kresge and L. E. Hakka, J. Amer. Chem. Soc., 88, 3868 (1966).
13. B. G. Ramsey, J. Amer. Chem. Soc., 88, 5358 (1966).
14. P. Schleyer, D. C. Kleinfelter, and H. G. Richey, Jr., ibid, 85, 479 (1963).
15. E. M. Arnett, Prog. Phys. Org. Chem., 1, (1963).
16. T. Yamaoka, H. Hosoya, and S. Nagakura, Tetrahedron, 26, 4125 (1970).